CHAPTER 3

STANDARD CONTROL LOOPS

1. GENERAL.

The standard control loops described in this chapter consist of control system equipment and devices, arranged to perform specific control system functions. In the ensuing discussions of the different types of control loops, all loop devices (including transmitters) are shown, and their associated indicators (such as thermometers) are included where required. The sensing elements are included with the transmitters and are not shown separately. Signals from the transmitters represent the changing conditions at the sensing elements. Also, the required panel-mounted and field-mounted pneumatic indicators are shown. Modulating control signals from controllers are converted from 4-20 milliamperes to 21-103 kPa (3-15 psig) by a current-to-pneumatic transducer (IP) connected to a positive positioner (PP) of a valve or damper actuator as applicable.

2. COOLING COIL TEMPERATURE CONTROL LOOP.

a. The cooling coil temperature control loop is a constant temperature control loop and is shown in figure 3-1. Temperature sensing element and transmitter TT sends a temperature signal to controller TC (or to the DDC panel), which modulates an IP. The pneumatic signal from the IP is connected to positive-positioner PP, which operates cooling coil valve VLV. The conditions that must be operative for the control valve to be controlled are: the supply fan is on and the control system is in the occupied mode.

b. A relay contact between TC and IP is open when either constraint is operative.

Figure 3-1. Cooling coil temperature control loop.

3. OUTSIDE AIR PREHEAT COIL TEMPERATURE CONTROL LOOP.

a. When the mixed air temperature of the outside air and the return air is too low, a preheat coil will be used to heat the outside air. This modulating control loop will be used only with hot water or hot glycol heating units. A variation of the preheat coil control loop for use with steam preheat coils is shown in chapter 5. The purpose of raising the mixed air temperature is to prevent freezing of chilled water coils and hot water coils downstream of the mixed air plenum. The coil is sized to raise the temperature of the maximum design quantity of outside air just high enough to bring the mixed air temperature within the range of 7 to 10 degrees C (45 to 50 degrees F). The loop controls the temperature of the air leaving the preheat coil before the air mixes with return air. The setpoint of the controller of this loop is the HVAC system designer's calculation of the coil discharge air temperature required to maintain a minimum temperature in the mixed air plenum when the outside air is at the coldest temperature. This setpoint assures an adequate minimum temperature entering the cooling coil of an HVAC system. The outside air preheat coil temperature control loop is shown in figure 3-2.

Figure 3-2. Outside air preheat coil temperature control loop.

b. A temperature sensing element and transmitter TT, in the discharge air stream from the preheat coil, sends a temperature signal to preheat coil temperature controller TC. Controller TC operates transducer IP to maintain the setpoint of the controller by modulating a valve VLV. Since the TC setpoint is normally in the range of 4.5 to 13 degrees C (40 to 55 degrees F), the valve is controlled during the heating season when the outside-air temperature is below the TC setpoint. When the outside air temperature is at or above the TC setpoint, VLV is closed.

c. In this control loop, TC is direct acting (DIR), and VLV is normally open (NO) and fails open under the pressure of the valve actuator's return spring upon loss of electric signal, pneumatic signal, or positive-positioner air supply. The purpose of this is to avoid freezing of the preheat coil and other coils in the HVAC system should such an event occur in cold weather.

d. The preheat coil control loop functions continuously, without regard to the operating condition of the HVAC system. This has the advantage of maintaining a minimum temperature in the ductwork when the HVAC system supply fan is off.

e. For DDC applications, the DDC panel takes the place of controller TC.

4. HEATING COIL TEMPERATURE CONTROL LOOP.

a. Heating coils in HVAC systems are usually controlled by either of the following methods:

(1) Coil discharge air temperature setpoint is fixed.

(2) Coil discharge air temperature setpoint is based on the outside air temperature. This is usually referred to as "set point reset" of the coil discharge air temperature according to a "reset schedule". Although set point reset can help to conserve energy through reduced piping system heat loss, its primary advantage is improved control system performance and occupant comfort (in multizone and dual duct systems) through improved temperature regulation as the downstream air dampers tend to modulate freely as system capacity better matches the load.

b. Figure 3-3 shows an example of set point reset of a heating coil (HC) temperature controller. The output of the reverse acting OA controller (TC) is the input to the control point adjustment (CPA) of the direct acting HC discharge air temperature controller (TC). As the outside air temperature increases, the output of the OA TC decreases, which causes the setpoint of the HC TC to decrease linearly. Alternatively, as the outside temperature decreases, the output of the OA TC increases, which causes the setpoint of HC TC to increase linearly.

Figure 3-3. Heating coil temperature control loop (scheduled from outside air temperature).

c. Figure 3-4 and Table 3-1 define an example setpoint reset schedule. The schedule requires that the discharge air set point not rise above 49°C (120°F) or below 32°C (90°F) and that there is a linear relationship between these two extremes.

Table 3-1. Setpoint reset schedule

Outside air temperature	HC discharge air temperature setpoint
-18°C (0°F)	49°C (120°F)
16°C (60°F)	32°C (90°F)

Figure 3-4. Outside air temperature controller input / output schedule.

d. To achieve the schedule defined in Figure 3-4 and Table 3-1, the controller parameters shown in Table 3-2 must be selected.

Table 3-2. Controller configuration parameters

Outside air temperature controller (TC REV)	Discharge air temperature controller (TC DIR)
Scaled low range of the PV input	Scaled low range of the PV input
Scaled high range of the PV input	Scaled high range of the PV input
Setpoint	Scaled low range of the CPA input
Proportional band	Scaled high range of the CPA input
Manual reset	Minimum setpoint (optional)
Minimum output	Maximum setpoint (optional)
Maximum output	

e. The PV input configuration parameters of both controllers must be selected so that the controllers scale their inputs to the ranges of their respective temperature transmitters. The outside air controller PV input low range and high range is -35°C (-30°F) and 55°C (130°F), at 4 and 20 mA, respectively. Similarly, the discharge air controller PV input low range and high range is 5°C (40°F) and 60°C (140°F), respectively. With these configuration parameters defined, the controllers scale, in a linear fashion, their PV input signals between 4 and 20 mA to the range of their corresponding temperature transmitters.

f. The discharge air temperature controller CPA input signal must be scaled independently of its PV input to recognize that a 4 mA signal at its CPA input from the outside air controller corresponds to a 32°C (90°F) discharge air setpoint. Likewise the discharge air controller must recognize that a 20 mA signal at its CPA input corresponds to a 49°C (120°F) setpoint. With these configuration parameters defined, the controller scales, in a linear fashion, CPA input signals between 4 and 20 mA. These CPA input low and high range configuration parameter selections are extracted directly from the reset schedule shown in Figure 3-4 and Table 3-1.

g. The discharge air temperature controller minimum and maximum setpoints can also be defined as 32°C (90°F) and 49°C (120°)F, but are optional since the full range of the CPA input has already been defined by the low and high range scale configuration parameters.

h. The outside air reset controller (TC REV) proportional band instructs the controller to change its output in proportion to its input. In our example, the outside air controller proportional band must be selected so that as the outside air temperature changes from -18°C (0°F) to 16°C (60°F) (also called the "throttling range", TR), the controller output changes full-scale from 20 to 4 mA. This signal is applied to the CPA input of the discharge air temperature controller, changing its setpoint from 49°C (120°F) to 32°C (90°F). The proportional band calculation was previously defined in equation 2-1 and in this example is:

$$PB = \frac{(TR\ x\ 100)}{T_s} \qquad \text{(eq. 2-1, repeated)}$$

$$PB = \frac{(16-(-16)°C)\ x\ 100}{55-(-35)°C} = 37.5\% \qquad PB = \frac{(60-0°F)\ x\ 100}{130-(-30)°F} = 37.5\%$$

i. The outside air reset controller (TC REV) setpoint is (arbitrarily) selected to be at the midpoint (50%) of the controller throttling range (TR). In our example, the throttling range is -18°C (0°F) to 16°C (60°F) as dictated by the reset schedule. Therefore the setpoint is -1°C (30°F).

j. The outside air reset controller (TC REV) manual reset value is selected to be 50% because the setpoint was selected to be at the midpoint (50%) of the throttling range. By definition of proportional control, to achieve the desired result, the outside air controller setpoint and manual reset values must be set to corresponding values, where in this case 50% was selected.

k. The outside air reset controller minimum and maximum output ranges must be selected to be 4 and 20 mA, respectively. Note that with some controllers this may be defined as 0 and 100% output, respectively. The minimum and maximum output range parameters ensure that the outside air controller output will change full range to correspondingly adjust the discharge air temperature controller setpoint over its full 32°C (90°F) to 49°C (120°F) range as defined in in the reset schedule.

l. Table 3-3 shows the final controller configuration parameter settings. These parameters and the reset schedule are to be shown on the control system Equipment Schedule drawing.

Table 3-3. Controller configuration parameters

Outside air temperature controller (TC REV)	Discharge air temperature controller (TC DIR)
Scaled low range of the PV input = -35°C (-30°F)	Scaled low range of the PV input = 5°C (40°F)
Scaled high range of the PV input = 55°C (130°F)	Scaled high range of the PV input = 60°C (140°F)
Setpoint = -1°C (30°F)	Scaled low range of the CPA input = 32°C (90°F)
Proportional band = 37.5 %	Scaled high range of the CPA input = 49°C (120°F)
Manual reset = 50 %	Minimum setpoint (optional) = 32°C (90°F)
Minimum output = 4 mA	Maximum setpoint (optional) = 49°C (120°F)
Maximum output = 20 mA	

m. The heating coil temperature control loop, with its fixed controller setpoints, is similar to the preheat coil temperature control loop in that it also controls the coil valve at all times. Figure 3-5 shows the heating coil controlled in a fixed temperature application. Temperature sensing element and transmitter TT sends a signal to heating-coil temperature controller TC. The operations of the control devices affected by the output signal of TC are identical, as previously described in paragraph 3-3.b. For DDC applications, the DDC panel takes the place of heating coil temperature controller TC.

Figure 3-5. Heating coil temperature control loop with heating coil controlled at a constant temperature.

n. The heating coil temperature control loop functions continuously, without regard to the operating condition of the HVAC system. This has the advantage of maintaining a minimum temperature in the ductwork when the HVAC-system supply fan is off.

5. MIXED AIR TEMPERATURE AND ECONOMIZER CONTROL LOOPS.

a. The use of up to 100 percent outdoor air to provide “free” cooling when the outdoor air conditions are favorable is called an economizer cycle. Whenever the enthalpy of the outdoor air is less than the enthalpy of the return air, conditions are favorable for an economizer cycle to provide cooling. While ideally the decision to allow the introduction of outside air beyond the minimum ventilation requirements for cooling would be based on a comparison of the enthalpies of the outside and return air, enthalpy sensors do not have the reliability of temperature sensors and they require more maintenance. Because of this, the economizer cycle discussed herein is based on a comparison of the temperature of the outside and return air. Furthermore the decision to enable an economizer cycle to operate is partially based on the temperature of the return air to determine whether the space requires heating or cooling. This decision process relies on a deadband between heating and cooling. Federal regulations (10 CFR 435) require the use of economizer cycles and deadbands between heating and cooling in most situations for all federally owned buildings.

b. The mixed air temperature and economizer control loops are shown in figure 3-6. The actuators on the dampers operate like the actuator on a control valve. The outside air damper and relief air damper are normally closed and operate in parallel with each other. The return air damper is normally open and works opposite to the outside air and relief air dampers. The mixed air temperature control loop is linked to the economizer control logic.

Figure 3-6. Mixed air temperature and economizer control loops.

c. Outside air will not be used when the control system is in the unoccupied mode or in the ventilation-delay mode. A normally open (NO) relay contact in the circuit to IP keeps the outside air damper closed under these conditions, and also when the supply fan is off. An open relay contact in the circuit between TC and high signal selector TY keeps the dampers open to the manual setting of minimum position switch MPS, when the system is in the minimum outside air mode, and the outside air damper is allowed to open by the absence of other constraints. When both of these relay contacts are closed, the control system is then operating in both the occupied and economizer modes. Controller TC maintains the mixed air temperature by controlling the IP to modulate the dampers beyond minimum position. The signal from MPS or the signal from TC operates through high signal selector TY to operate the IP, which sends a pneumatic signal to positive-positioner PP to control the damper actuators. The output of IP to the damper actuator positioners can be read on PIs at the panel and at the damper location. Mixed air temperature sensing element and transmitter TT sends a signal to TC, which changes its output to operate the dampers between minimum outside air position and full outside air.

d. The temperature sensing elements and transmitters TT in both the outside air intake and the return air duct send temperature signals to economizer controller EC.

e. The economizer controller EC requires a setpoint for each of two contacts that determine whether the coil of the relay that puts the system in the economizer mode is energized or de-energized. The setpoints and switching differentials for each of the contacts are adjustable in EC. One of the contacts, configured as a PV contact, responds to the temperature sensing element and transmitter TT in the return air duct and prevents the economizer mode from operating when the HVAC system is heating the space that it serves. The return air temperature setpoint of the contact will be selected at a temperature that is below the expected cooling season return air temperature but higher than the expected heating season space temperature. Two-deck multizone and dual-duct multizone systems present a special situation and will be discussed separately. The other contact, configured as a deviation (DEV) contact, responds to the difference in the signals of outside air temperature and return air temperature. The setpoint of the DEV contact requires a calculation by the designer. The designer will indicate the return air temperatures at which the PV contacts open and close and the temperature differences between the outside air temperature and the return air temperature at which the DEV contacts open and close.

f. In two-deck multizone and dual-duct multizone systems, given that there is no deadband between heating and cooling, there may not be sufficient change in the return air temperature between heating and cooling seasons to provide an indication as to what mode the system is in (heating or cooling). (Note that the use of two-deck or dual-duct multizones does not comply with federal regulations (10 CFR 435) which require a deadband between heating and cooling; a bypass multizone is a better choice and allows for the use of a deadband.) After evaluating several alternative methods for economizer mode initiation, the method described herein was judged to be the simplest and most reliable, and is therefore the recommended method.

We will look at two situations: 1) the unit is either served by a dual-temp hydronic system, or HW and CHW availability is seasonally scheduled (i.e.- only HW is available during the heating season and vice versa), and 2) HW and CHW are both available year-round.

Case 1: Dual-temp hydronics or scheduled HW & CHW - Make the "cooling mode" decision based on OA temperature rather than RA temperature. (i.e. - If OA is above X degrees, then assume the space needs cooling.) In this case, the outside air temperature would be the PV input to EC and the return air temperature would the CPA input to EC. The outdoor air temperature above which the space will require cooling could be determined using computer models; however, the value would change as internal loads changed. In practice, it would seem that an engineering judgement should be made initially and adjusted later if required.

Case 2: Simultaneous availability of HW and CHW - In this case it is recommended that an economizer cycle not be used. An example system which does not utilize an economizer cycle is depicted in Chapter 5.

g. Because of the difficulty of maintaining enthalpy based economizer switchover hardware, the economizer controller operation is based on dry bulb temperature measurements rather than enthalpy measurements. The comparison of outside air and return air temperatures for determining the economizer switchover point is a method of control that uses local weather data for selecting an optimum dry-bulb temperature difference. An explanation of this method begins with figure 3-7.

Figure 3-7. Design condition for economizer mode operation.

h. The skeleton psychrometric chart shows a return air design condition of 24 degrees C (75 degrees F) dry-bulb temperature and 50 percent relative humidity (point A). A constant enthalpy line (B-C) drawn through this condition divides the chart into 4 regions of outside air temperatures and outside air relative humidities, which are:

(1) Region A, in which temperature and enthalpy conditions are less than return air design conditions.

(2) Region B, in which temperature conditions are lower but enthalpy conditions are higher than return air design conditions.

(3) Region C, in which both temperature and enthalpy conditions are higher than the return air design conditions.

(4) Region D, in which temperature conditions are higher but enthalpy conditions are lower than return air design conditions.

l. Cooling energy can be saved by using outside air for cooling when outside air conditions are in region A. Less energy will be used in cooling outside air than in cooling return air when outside air conditions are in region D. When outside air conditions are in region B, the outside air dry-bulb temperature is less than the return air dry-bulb temperature; however, excess cooling energy would be used if more than the required minimum of outside air is used, because the enthalpy of the outside air is higher than the design return air condition. When outside air conditions are in region C, there is no energy saving available from the use of outside air.

j. Figure 3-8 illustrates the method for selection of a setpoint for the DEV contact for economizer mode switchover in a relatively humid southeastern United States city, based on the published weather data in TM 5-875. The designer will consult the local weather data for the nearest location of the project. The method presumes that the location is such that an economizer mode is acceptable in the HVAC design because it would not place an energy burden on the system due to a requirement for humidification of more than the minimum quantity of outside air. Using a psychometric chart, the designer will use the following procedure to determine the setting of the DEV contact:

(1) Plot a constant-enthalpy line (B-C) through the return air design temperature and relative-humidity condition (A). If the outside air conditions are below this line, the total heat content of the outside air is less than that of the return air and it can be used for cooling.

(2) Plot an average-weather line (E-F) by using the midpoint of the 2.8 degree C (5 degree F) bin and the mean coincident wet-bulb temperature for that temperature bin from TM 5-785.

(3) Read the difference in dry-bulb temperature between the design return air temperature and the outside air temperature where the average-weather line crosses the constant-enthalpy line (D-G).

(4) Use this difference in dry-bulb temperatures as the setting for the DEV contact.
The temperature differential setpoint of the DEV contact is shown as 4.5 degrees C (8 degrees F). However, the temperature differential determined by this method will vary with: the design return-air conditions; and the average weather line for the locality. Less-humid climates will tend to shift the average weather line downward toward the design return air condition, which would result in a smaller differential. The effect on energy conservation of using this method is shown in figure 3-9.

Figure 3-8. Selecting the economizer switchover point.

Figure 3-9. Effect on energy conservation of selection of the economizer switchover point.

k. Figure 3-9 shows that the dry-bulb temperature line at the intersection of the average weather line and the constant enthalpy line bisects region B. The area shown as region B-1 represents outside air conditions when the economizer mode will not save cooling energy even though outside air beyond the minimum quantity will be used if the control system modulates the dampers open. The area shown as region A-1 represents outside air conditions when the economizer mode will save cooling energy. The net effect on energy use depends on how many operating hours per year of the HVAC system are coincident with the occurrence of the outside air conditions of region B-1.

l. For DDC applications, the high-signal selector TY, the minimum position switch MPS, the mixed air temperature controller TC, and the economizer controller EC will not be required, as these functions are performed in software in the DDC panel. The logic remains the same as for control via single-loop controllers. Thus, the design will include temperature transmitters in the mixed air, in the return air, and in the outside air which will provide input to the DDC panel which operates the outside air damper, the return air damper, and the relief air damper according to the logic described above.

6. MINIMUM OUTSIDE AIR CONTROL LOOP FOR VAV HVAC SYSTEMS.

a. ASHRAE standard 62-1989, "Ventilation for Acceptable Indoor Air Quality", defines recommended quantities of ventilation air for various building types. Guidelines provided by standard 62-1989 were set forth with the intent of helping to improve indoor air quality. It is important to maintain the minimum amount of outside air quantity introduced into a building due to the potential health damaging effects that inadequate fresh outside air (OA) quantities may have on building occupants. In addition, introducing OA quantities in excess of the minimum can waste energy.

b. Variable air volume systems are particularly problematic due to the fact that the air flow quantity changes with changes in system load. Included here is the recommended technique for control of minimum outside air quantity in VAV systems. Use of other schemes to control fresh air quantity is discouraged, including schemes that use CO_2 sensors. This technology in HVAC applications has not matured. The accuracy, reliability, and cost effectiveness of CO_2 sensing devices is in question and is presently being investigated.

c. In the past, the minimum outside air quantity for VAV systems was established during system balancing by setting the minimum position of the outside air (OA) damper at maximum fan turndown. This is accomplished with all the zone terminal units positioned to provide minimum airflow while maintaining the duct static pressure control setpoint. This approach helps to ensure that an adequate quantity of outside air is supplied to the building during normal operation of the system, but because the damper position is fixed, during periods of increased load, the minimum outside air quantity is exceeded as the fan speed and therefore system air volume is increased. This is energy intensive.

d. Since the issue of indoor air quality began to receive more attention, the industry consensus is that a better approach for ensuring adequate ventilation is to maintain the outside air quantity based on direct measurement and control of the volumetric outside air flow. This is accomplished using a separate duct section through which the OA air volume is measured using an air flow measurement array (AFMA) and is illustrated in figure 3-10. The AFMA flow transmitter output is sent to a PI controller (FC) which modulates a minimum OA damper located downstream of the AFMA to control the OA flow quantity at the controller setpoint. In DDC applications, the DDC panel takes the place of the flow controller FC. Note that two separate duct sections are used to help ensure accurate control of the minimum outside air quantity. The second outside air duct is utilized during economizer operation and is controlled the same as previously discussed.

Figure 3-10. Minimum outside air and mixed air temperature/ economizer control loops for VAV systems.

e. Early in the system design process, the designer must give consideration to the space requirements necessary to successfully implement minimum outside air flow control. The OA ductwork must be long enough to permit accurate measurement by the AFMA. The minimum functional length of the ductwork section between the upstream weather louver and the AFMA is two times the equivalent duct diameter. Transition angles leading to the AFMA should not exceed 15 degrees. The minimum functional length of the ductwork section between the AFMA and the downstream control damper is one half the equivalent duct diameter. Do not locate control dampers upstream. These distances assume that an AFMA with multiple sensors and an air straightener is used. It is recommended that an access door be located immediately upstream of the air flow station.

f. The minimum OA duct section should be sized for the condition where the main OA damper is closed and the return air damper is open with the fan speed at minimum load turn down. Under this condition the flow through the minimum OA duct is at maximum. The recommended duct sizing range is between 1.5 and 2 m/s (300 and 400 fpm) at the location of the AFMA. Louver openings should be sized in accordance with ASHRAE recommendations such that they limit louver face velocity to 2 m/s (400 fpm) or less. Pressure drop across the air flow measurement array plus air flow straightener can be estimated to be 1 Pa (0.003" wc) at 2 m/s (400 fpm).

g. Pitot tube type AFMAs are not recommended for use in outside air measurement applications, as their minimum measurable air flow velocity is approximately 3.5 m/s (700 fpm). Pitot tube AFMAS are also more inclined to be adversely affected by airborne contaminants.

h. Electronic AFMAs, by design, are resistant to airborne contaminants, but the station is to include a honeycombed airflow straightening device located immediately upstream of the AFMA. The airflow straightener helps to remove turbulent and rotational air flow. The honeycombs are specified to be 3 mm (1/8 inch) diameter, presenting the potential for clogging by bugs and other particulate matter. Because of this, filter media are to be used, located no less than 1 m (39) inches upstream of the AFMA.

I. Exhaust fans impact building ventilation because they can remove significant volumes of air from a building. This exhaust must be considered in determining the quantity of air to be returned to the air handling unit. To help ensure a small positive building pressure, slightly more air must be supplied than is returned. If a return duct is used, size it to account for exhaust fan and exfiltration losses.

j. When a return fan is used, determine the differential volume flow rate (bias) between the supply and return ducts by taking into account the exhaust from the supplied spaces. The bias setting will be slightly larger than the total building exhaust. Making the bias slightly larger than the maximum exhaust will help to ensure positive building pressure and adequate ventilation. Refer to section 8 - RETURN FAN VOLUME CONTROL LOOP for additional guidance on selection of the return fan bias setting.

7. SUPPLY DUCT STATIC PRESSURE CONTROL LOOP. The supply duct static pressure control loop is shown in figure 3-11. A differential pressure sensing element and transmitter (DPT) sends a signal to static pressure controller PC, which operates IP to control DA, which in turn operates fan inlet vane IV provided that the fan is on. DPT must have a relatively low range, such as 0 to 500 Pa (0.0 to 2.0 inches of water column). The supply fan may have been selected for a much larger static pressure, but the static pressure at the location of the DPT's sensor is typically 250 to 375 Pa (1.0 to 1.5 inches of water column). The recommended sensing location of DPT is approximately 75 to 100 percent of the distance from the first to the last air terminal unit along the duct calculated to have the greatest pressure drop. This sensing location insures that the static pressure will be controlled at the value required to enable all

VAV boxes to function. The "Fan-On" relay contact disconnects PC from IP, causing DA to hold IV in the closed position (unloaded) on fan shutdown; the purpose in unloading the fan is to allow it to start unloaded. DPI is a low differential pressure gauge used as an indicator for DPT. Details of the action of the rest of the control system devices connected to the IP's output are similar to comparable parts of other loops previously described. For DDC applications, the DDC panel takes the place of the static pressure controller PC.

Figure 3-11. Supply duct static pressure control loop.

8. RETURN FAN VOLUME CONTROL LOOP. The return fan volume control loop is shown in figure 3-12. Flow sensing elements and linearized transmitters FTs in the supply air and the return air get signals from duct-mounted air flow measurement stations and sensing arrays, AFMA. Both FTs send signals to controller FC. These signals are the information necessary to maintain a fixed flow difference (in L/s (cfm)) between the supply air and return air ducts. The controller measures and controls the return air flow through the PV input based on the supply air flow measured at the CPA input. More than likely, the ranges of the air flow velocities in each duct will be different because of differences in design velocity and in the cross-sectional areas of the ducts. The FTs in the supply air duct and return air duct may or may not have the same span and range. This means that a given flow rate in the supply duct may have a different signal level than the exact same flow rate in the return duct. In order for FC to control the return air flow at a specific rate (L/s (cfm)), the CPA signal from the supply fan FT must have the same value that will appear at PV when the setpoint is achieved. To achieve this, the CPA signal from the supply duct must be converted by FC's ratio and bias feature to perform two functions. A ratio factor must be applied to the signal from the supply air flow transmitter/air flow measurement station (FT/AFMA) combination so that it will match the signal range of the return air FT/AFMA combination. Also, the ratio is used to account for differences in the cross-sectional area of the ducts at the locations of the measuring stations. The signal must then be biased to maintain the design fixed air flow difference. For example, if the fixed difference is required to be 1415 L/s (3,000 cfm) for minimum outside air requirements when the supply air flow is 9440 L/s (20,000 cfm), CPA tells FC to control PV at 8025 L/s (17,000 cfm); when the supply air flow is 5900 L/s (12,500 cfm), CPA tells FC to control PV at 4485 L/s (9,500 cfm). The 1415 L/s (3000-cfm) difference is the bias to be set in the controller in L/s (cfm) units. The CPA signals at two such supply air flow points must match the PV signals at two corresponding return air flow points. When this is achieved at two points, the required results will be achieved for any supply fan flow and the appropriate return fan flows within the turndown capabilities of the return fan. The ratio can be calculated according to equation 3-2. Equation 3-2 assumes that the low end of the transmitter span is 0 m/s (0 fpm) at 4 milliamperes for each transmitter.

$$R = \frac{A_s/A_r}{V_s/V_r} \qquad \text{(eq. 3-2)}$$

Where:

R = Ratio (dimensionless)
As = Area of supply air duct at the measuring station (sq m (sq ft)).
Ar = Area of return air duct at the measuring station (sq m (sq ft)).
Vs = Span of the flow transmitter in the supply duct (m/s (fpm)).
Vr = Span of the flow transmitter in the return duct (m/s (fpm)).

The bias is set in the controller in L/s (cfm) units. Selecting the bias value requires consideration of the exfiltration flow ($Flow_{exf}$) required to pressurize the space and the space exhaust flow ($Flow_{exh}$) (such as that from toilet areas) as follows:

$$Bias = Flow_{exf} + Flow_{exh}$$

Where:
$Flow_{exf}$ = Space exfiltration flow, L/s (cfm)
$Flow_{exh}$ = Space exhaust flow, L/s (cfm)

Determination of the exhaust flow is straightforward. It is the total flow due to exhaust fans located in the space served by the air handling unit. Determiming the exfiltration flow can be slightly more involved and is related to building pressuization. Detailed guidance in determining this value is presented in PROSPECT course 340 “HVAC Control Systems Design”, although a reasonable approximation can be obtained by assuming that the $Flow_{exf}$ is 10 to 15 percent of the design airflow quantity. Use 10 percent for a tight building and 15 percent for a loosely constructed building.

The bias quantity should be coordinated with the minimum outside air flow quantity as follows:

MIN OA = $Flow_{ventilation}$ if $Flow_{ventilation} > Bias$
Or:
MIN OA = Bias if $Flow_{ventilation} < Bias$

Where:
$Flow_{ventilation}$ = Fresh air ventilation quantity (per ASHRAE Standard 62), l/s (cfm)
Bias = $Flow_{exf} + Flow_{exh}$, l/s (cfm)
$Flow_{exf}$ = Building or space exfiltration flow, l/s (cfm)
$Flow_{exh}$ = Building or space exhaust flow (ie. Toilets, etc), l/s (cfm)

For DDC applications, the DDC panel takes the place of flow controller FC. The ratio and bias logic remains the same as for control via single-loop controllers, but is performed in software.

Figure 3-12. Return fan volume control loop.

9. HUMIDIFIER CONTROL LOOP. The humidifier control loop is shown in figure 3-13. Humidifier control valve VLV is normally closed. It is inhibited from opening by the contact of a relay that is open unless the fan is on, the system is in the occupied mode, and the ventilation delay period has expired. When these conditions of operation are met, space relative-humidity sensing element and transmitter RHT signals relative-humidity controller RHC to operate IP to control humidifier valve VLV. A high-limit relative-humidity controller RHC receives a signal from a duct relative-humidity sensing element and transmitter RHT downstream of the humidifier. Both controllers are reverse-acting. Low-signal selector RHY allows the space relative-humidity controller to operate the valve if the high-limit relative-humidity setpoint is not exceeded. The high-limit relative-humidity controller must be a proportional only controller. For DDC applications, the DDC panel takes the place of the two relative humidity controllers RHC and the

low-signal selector RHY. Low signal selection is performed in software.

Figure 3-13. Humidifier control loop.

10. THE TYPICAL SCHEMATIC.

a. The integration of standard control loops into a standard system starts with a schematic. A typical schematic for single-loop controller applications is shown in figure 3-14 and for DDC applications is shown in figure 3-15.

Figure 3-14. Typical single-loop controller schematic.

Figure 3-15. Typical DDC schematic.

b. Figure 3-14 shows the control loops arranged around an airflow diagram. When showing the schematic, the designer will:

(1) Label all HVAC equipment.
(2) Label each control device with a unique identifier.
(3) Label the action (NC or NO) of all valves, dampers, and other appropriate devices.
(4) Label the action of all controllers as direct-acting DIR or reverse-acting REV.
(5) Label the input of all controllers (PV or CPA).
(6) For each device that operates contacts, show a line number on which each contact will appear on a ladder diagram.
(7) For each relay contact, show the line number of a ladder diagram on which the relay operating coil will appear.
(8) Show the location of all instruments not located in the flow stream or in the HVAC control panel.
(9) Show a graphic representation of sequencing operations with open and closed positions versus controller output and space temperature.

11. THE TYPICAL LADDER DIAGRAM.

a. When all the information necessary for a description of the system is not shown on the schematic, a ladder diagram will be required for single-loop controller applications. As the logic is performed in software, no ladder diagram is required for DDC applications.. A typical ladder diagram is shown in figure 3-16.

Figure 3-16. Typical ladder diagram.

b. In the ladder diagram, the designer will:

(1) Show a section of the diagram for the HVAC control panel logic.
(2) Show a section of the diagram for each starter control circuit and interlock circuit for HVAC equipment.
(3) Label control devices and relays with their unique identifiers.
(4) Label magnetic starter coils.
(5) If multiple control devices of the same type (such as low temperature protection thermostats or smoke detectors) are required, assign a unique identifier for each and show its contact.
(6) Show separate relays to control ac and dc circuits.
(7) Number the ladder diagram lines according to their control power source.
(8) Show a switch, located in the HVAC control panel, to override the clock (or EMCS) and to be used to place the control system in continuous occupied mode (auto/auto override).
(9) Show a switch, located in the HVAC control panel, that can be used to shut down HVAC equipment and interlocked equipment (off/enable).

c. The HVAC control panel section of the ladder diagram will be in accordance with the following format:

(1) Line numbers will start with 0 for the clock circuit and continue as required.
(2) Control system switches and contacts will be shown on the left of the diagram.
(3) Relay coils will be shown in the center of the diagram, centered below the clock circuit.
(4) Pilot lights will be shown on the right of the diagram.
(5) Contacts available to EMCS will be shown outside the ladder and to the right of the diagram.

d. Each section of the HVAC equipment starter control circuits and interlock circuits will be in accordance with the following format:

(1) The line numbers of the first section will begin with 100, the second section with 200, and subsequent sections with appropriate higher numbers in increments of one hundred.
(2) Magnetic starter circuits will show one phase powering a control circuit transformer, switches, fuse, and overload relays.
(3) The panel ladder diagram will have a jumper shown for connection to EMCS of an economizer enable and disable function. The panel ladder diagram will show terminal points for remote system shutdown and remote safety override control of HVAC system fans.
(4) Starter ladder diagrams will have an off-enable switch to allow HVAC system motors to be stopped from the HVAC control panel.

12. THE TYPICAL EQUIPMENT SCHEDULE.

a. An equipment schedule is required to show the control system parameters not shown on the schematic and the ladder diagram. Not all HVAC control devices shown on the schematic and the ladder diagram are included in the equipment schedule because it is not necessary to show parameters for them. Control devices that are excluded from the schematic are relays, IPs, loop drivers, and signal selectors. A typical equipment schedule is shown in figure 3-17.

Figure 3-17. Typical equipment schedule.

b. In the equipment schedule, the designer will:
(1) Arrange all control devices by loop function.
(2) Show the unique identifier as the device number.
(3) Name the device function.
(4) Show setpoints, ranges, time schedules, and other parameters.
(5) Show the selected Cv and required close-off pressure for each valve.

13. THE TYPICAL DDC DATA TERMINAL STRIP (DTS) LAYOUT.

For DDC applications, a data terminal strip layout is required to show all connections for inputs and outputs (also referred to as "points") to the system. Each DDC panel should have a corresponding DTS. The layout should show the terminals numbered, show the device number (from the schematic) which is connected to the terminals, have a description of the device and indicate whether each point is an analog input, an analog output, a digital input, or a digital output. It is a good idea to include 25 percent of the terminals as "spares". A typical data terminal strip layout is shown in figure 3-18.

Figure 3-18. Typical DDC data terminal strip layout.